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EFFECT OF EXTERNAL PRESSURE ENVIRONMENT ON THE INTERNAL NOISE LEVEL DUE TO A SOURCE INSIDE A CYLINDRICAL TANK

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SUMMARY

A small cylindrical tank was used to study the effect on the noise environment within a tank of conditions of atmospheric (sea level) pressure or vacuum environments on the exterior. Experimentally determined absorption coefficients were used to calculate transmission loss, transmissibility coefficients and the sound pressure (noise) level differences in the interior. The noise level differences were also measured directly for the two exterior environments and compared to various analytical approximations with limited agreement. Trend study curves indicated that if the tank transmission loss is above 25 dB, the difference in interior noise level between the vacuum and ambient pressure conditions are less than 2 dB.

INTRODUCTION

To ensure acceptable vibroacoustic levels for hearing, communication, performance, comfort and sleep, it will be necessary to develop prediction methods and control techniques for use in the design and operation of future space stations. On a number of previous space vehicles, noise and vibration levels have exceeded design specifications and evoked crew complaints. These cases indicate that the design specifications were probably inadequate for space applications since they were based on criteria derived from earth conditions and indicate the need for better prediction and control.

The current effort was undertaken to study the effect of an external vacuum environment on the internal noise levels of a small unstiffened monocoque cylinder. Differences in noise levels were determined by 1) calculating the difference in interior noise level for the two external pressure conditions using reverberant room acoustic theory with assumed absorptivity and transmissibility

coefficients, 2) calculating the differences using measured absorptivity, and 3) direct measurements of noise levels. The results of calculations and measurements are compared. Calculated curves of differences in noise levels as a function of absorptivity and transmission loss are also shown.

EXPERIMENTAL METHOD

Interior noise measurements were made within an unstiffened cylindrical tank (52.7 cm long and 25.4 cm radius) whose internal pressure was held at atmospheric pressure both while the tank was soft-mounted in ambient air and in a 244 cm (8 ft) diameter spherical vacuum chamber at 10 mm pressure. The following sections discuss the experimental test set-up, the instrumentation for obtaining the noise results, the measurements, and data reduction.

Experimental Test Set-up

The experimental set-up of the tank in the spherical vacuum chamber is shown diagrammatically in figure 1. Within the tank volume are a speaker and two microphones. One microphone is located 5 cm from the top at the center of the tank and the other was 5 cm from the side of the tank and 10 cm down from the top. The tank is vented to the atmosphere. A pressure gage is monitored to be assured that the tank remains at atmospheric pressure when the sphere is evacuated.

A photograph of the test apparatus is shown in figure 2. The electrical power and signal leads as well as the vent tube and pressure gage may be observed at the bottom of the tank. The tank dimensions and construction details are given in figure 3.

Instrumentation

A photograph of the recording and monitoring instrumentation is shown in figure 4. The speaker within the tank was driven by a random or a sinusoidal noise generator and an amplifier. The voltage and current to the speaker were

monitored by a digital voltmeter and a digital ammeter. The twin-beam oscilloscope was used to monitor the input or output signals. The output signals of the two microphones shown in figure 1 were recorded on a 2-channel plus voice track audio tape recorder. Microphones, shown on the instrument table, were used for annotating the audio tape recorders. In addition, a narrow-band frequency analyzer and plotter were utilized.

Measurements

Two sets of measurements were obtained. One set was obtained by applying noise, band-limited from 20-5000 Hz, to the interior of the tank. The resultant signals from each microphone were transformed and averaged for 4 minutes to obtain a frequency spectrum. The frequency spectrum was transferred to the plotter (sample shown in figure 5). To aid in the intepretation of the peaks in figure 5, the low order resonant frequencies for the longitudinal, radial, and circumferential acoustic modes and the structural ring mode were calculated and are shown in figure 6. The test was repeated by applying a sinusoidal input to the speaker at each of the resonant frequencies as determined from the first set of measurements. The tape recorder was started and the power to the speaker was abruptly terminated causing a sound decay in the tank. These decay data were subsequently analyzed utilizing a graphic level recorder (sample shown in figure 7). Reverberation time measurements were determined for both microphones at each selected frequency. These measurements were used for calculating absorption coefficients as described in the next section.

Data Analyses

The data were analyzed in two parts. The first part consisted of comparisons of the noise levels under both ambient and vacuum conditions at each of the resonant frequencies to determine the effect of the external vacuum on the tank interior noise.

The second part was to determine the reverberation time (T) for the noise level to drop 60 dB from the initial noise level at the termination of the driving noise. The time was obtained from the slope of the decay curve (figure 7). From the reverberation time, other parameters, namely ambient and vacuum absorption coefficients, transmissibility, and transmission loss were calculated. The following expressions were used to relate these parameters and the difference in interior noise level for the external vacuum and ambient pressure conditions.

$$\Delta = 10 \log_{10} \frac{\alpha_a}{\alpha_v} \qquad (1)$$

$$\alpha_a = \alpha + \tau \qquad (2)$$

$$\alpha_v = \alpha \qquad (3)$$

$$T = \frac{0.161V}{\alpha A} \qquad (4)$$

$$\Delta = 10 \log_{10} \frac{T_v}{T_a} \qquad (5)$$

$$TL = 10 \log_{10} \frac{1}{\tau} \qquad (6)$$

Where Δ = difference in interior sound pressure level between vacuum (v) and ambient (a) external pressure environment, dB.

α = absorptivity coefficient, energy absorbed/energy incident.

τ = transmissibility coefficient, energy transmitted/energy incident.

TL = transmission loss, dB.

T = reverberation time, time for sound pressure level to drop 60 dB, sec.

V = Volume of cylinder, m^3 (0.103 m^3).

A = Surface area of cylinder, m^2 (0.811 m^2).

subscripts a = ambient
v = vacuum

RESULTS AND DISCUSSION

The results of this investigation are shown in figures 8-14. The direct measurements of interior noise level differences, delta (Δ) are shown first. Then the measurements of reverberation times leading to transmissibility coefficients, transmission loss, and noise level differences are discussed. Three methods of determining noise transmission loss (references 1-3) were used in the calculations shown for comparison. The paper is concluded with a trend study of differences in interior noise levels as a function of the noise absorptivity and transmission loss.

Direct measurements of Δ are shown in figure 8 for the two microphones with the cylinder. Resonant frequencies were determined from the measured frequency spectrum within the tank at which Δ could be measured. Deltas exceed 3 dB at only two frequencies. Both frequencies are close to the ring frequency of the tank (3129 Hz at both ambient and vacuum conditions).

Indirect measurements were used to obtain delta from noise reverberation time measurements. In addition, these reverberation time measurements were used to calculate the noise absorption coefficients, transmission loss, and transmissibility coefficients. The calculated absorption coefficients averaged for both microphones are shown in figure 9 for both ambient and vacuum exterior conditions. As expected, the absorption coefficient for ambient pressure conditions was always higher than for the vacuum condition at the same frequency. Also shown for comparison is the assumed average ambient acoustic absorption coefficient (solid line) obtained from the literature for standard atmospheric conditions.

The values of transmission loss (TL) obtained from the reverberation time measurements are shown in figure 10 (indicated as "experiment"). These values were obtained by calculating τ from equation 2 and TL from equation 5. It may be

noted that the values of transmission loss are all moderately high, from 16 to 35 dB. Also, for comparison purposes, calculated values of transmission loss using three approximate methods are shown. The solid curve (based on the method of reference 1) was obtained for an infinite plate having the same mass per unit area as the cylindrical tank. The value of transmission loss becomes small as the frequency decreases toward zero. The long dashed curve (based on the method of reference 2) was calculated for the transmission loss of noise within an equivalent cylinder but of infinite length. This curve has its lowest values of transmission loss in the range of 1300 to 3000 Hz. The third curve (based on the method of reference 3) was calculated for the transmission loss of a cylinder open at one end of the same thickness and diameter as reference 2 but of a length of 304.8 cm. However, the noise source was in the closed end of the cylinder. The values of transmission loss were approximately 19-32 dB in the range of frequencies from 400 to 5000 Hz. Below 400 Hz, the values of transmission loss increase very rapidly. It may be observed that there is limited agreement between the experimentally obtained values and the results of calculations.

The values of transmission loss are converted to transmissibility coefficients and are shown in figure 11. Now it can be seen that the experimentally obtained coefficients are small (<0.022). Only the method of reference 3 indicates that the coefficients would be small throughout the frequency range. Reference 2 indicates that the coefficients would be small in the frequency ranges up to 1000 Hz and from about 3600 to 4000 Hz. The method of reference 1 indicates that the coefficients would be small in the range from 800 to 5000 Hz.

Differences in interior noise levels (Δ) from exterior vacuum to ambient pressure conditions were calculated and are shown in figure 12. Results for the three referenced methods were obtained by utilizing assumed values of absorptivity

shown in Figure 9. Experimentally obtained deltas from reverberation time measurements are shown and compared to the deltas directly measured from the random noise input in the clyindrical tank. The two sets of measured deltas agree very well with each other except near the ring frequency of the tank. Also, except near the ring frequency, no measured delta is greater than about 3.5 dB. A comparison of these data with the deltas obtained from the approximations based on the three referenced methods indicate limited agreement. The method of reference 1, below 500 Hz, indicates much higher values, and from 2000 to 5000 Hz, indicates lower values than experimentally obtained. At a very low frequency, a delta of 12 dB is indicated. The method of reference 2 indicates limited agreement throughout the frequency range. The values obtained using the method of reference 3 are consistently lower than those experimentally obtained with the highest delta about 1 dB.

Figures 13 and 14 show trend studies. As may be noted from the section on data analysis, the absorption coefficient of a structure in the earth's ambient environment (α_a) is greater than the absorption coefficient of the structure in a vacuum (α_v) by the amount of the transmissibility τ (equations 2 and 3). Calculations were made (equation 1) to determine Δ as a function of the absorption ratio (ambient absorption to vacuum absorption). Results are shown in figure 13. For high ratios (over 10), one would expect delta to be greater than 10 dB. However, transmissibility coefficients measured in this study were very low (see figure 11) which resulted in absorption ratios in the range of 1 to 3. The corresponding deltas are in the range of zero to 3-4 dB.

As would be expected, delta is a function of transmission loss of the structure as shown in figure 14. The curves shown are for constant acoustic absorption coefficients of the structure when the tank has an external ambient (earth) environment. It is seen that if the transmission loss is above 25 dB,

delta will be less than 2 dB even if the ambient absorption coefficient α_a is as low as 0.01. For higher α_a's, even lower transmission loss values are required to obtain sizable deltas. Thus, figures 13 and 14 help explain why the small values of Δ were obtained in this study.

CONCLUDING REMARKS

A small cylindrical tank containing a speaker and two microphones was used to study the effect of a noise environment within the tank under both earth's ambient pressure condition and vacuum environment on the exterior. Experimentally measured reverberation times were used to calculate absorption coefficients, transmission loss, transmissibility coefficients, and deltas (sound pressure level differences) in the interior noise level of the tank. Deltas were also measured directly for the exterior environments and compared to various analytical approximations with limited agreement. Trend study curves indicated that if the tank transmission loss was large (above 25 dB), deltas are less than 2 dB.

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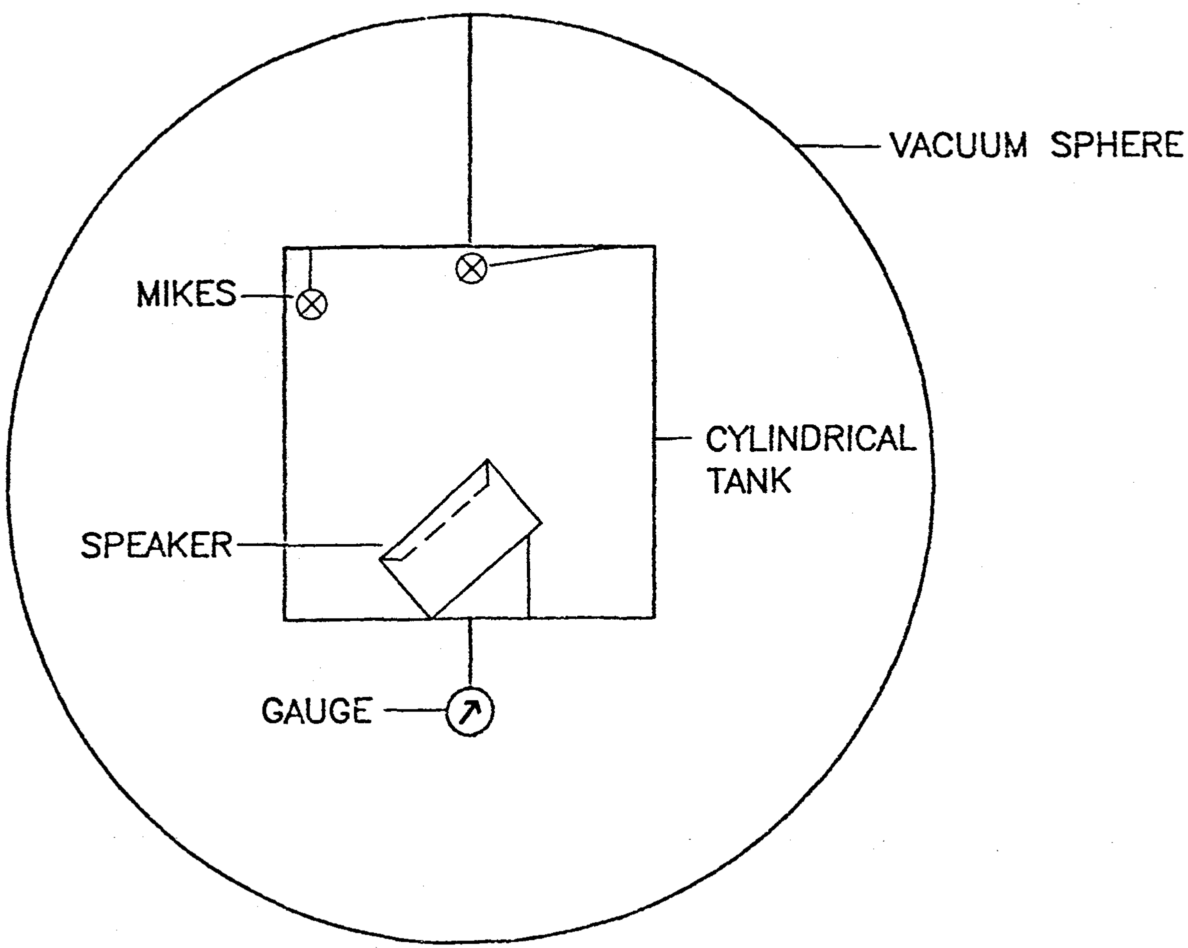

Figure 1.- Diagrammatic sketch of cylindrical tank in a 244 cm diameter spherical vacuum chamber.

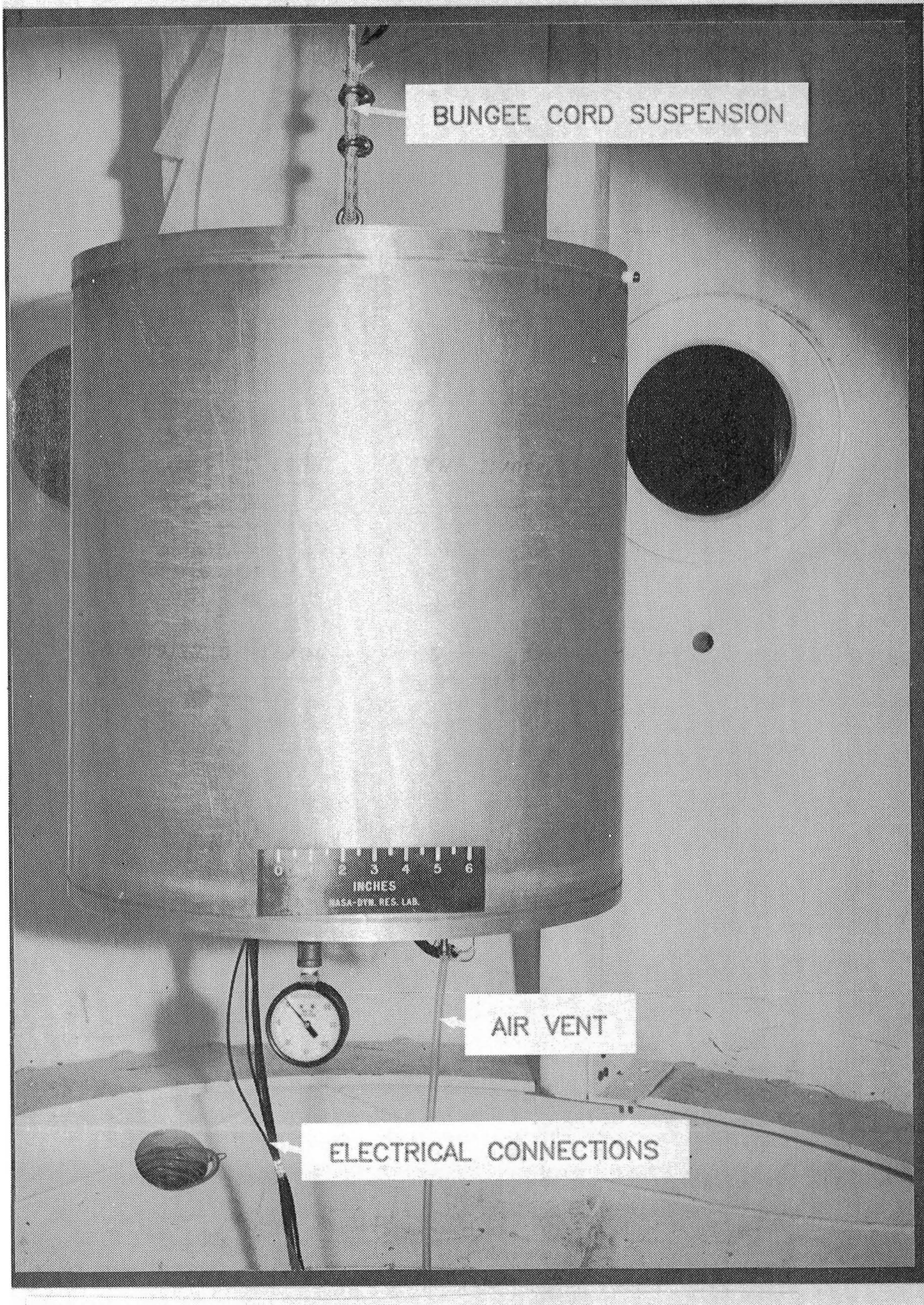

Figure 2.- Cylindrical tank suspended in vacuum chamber.

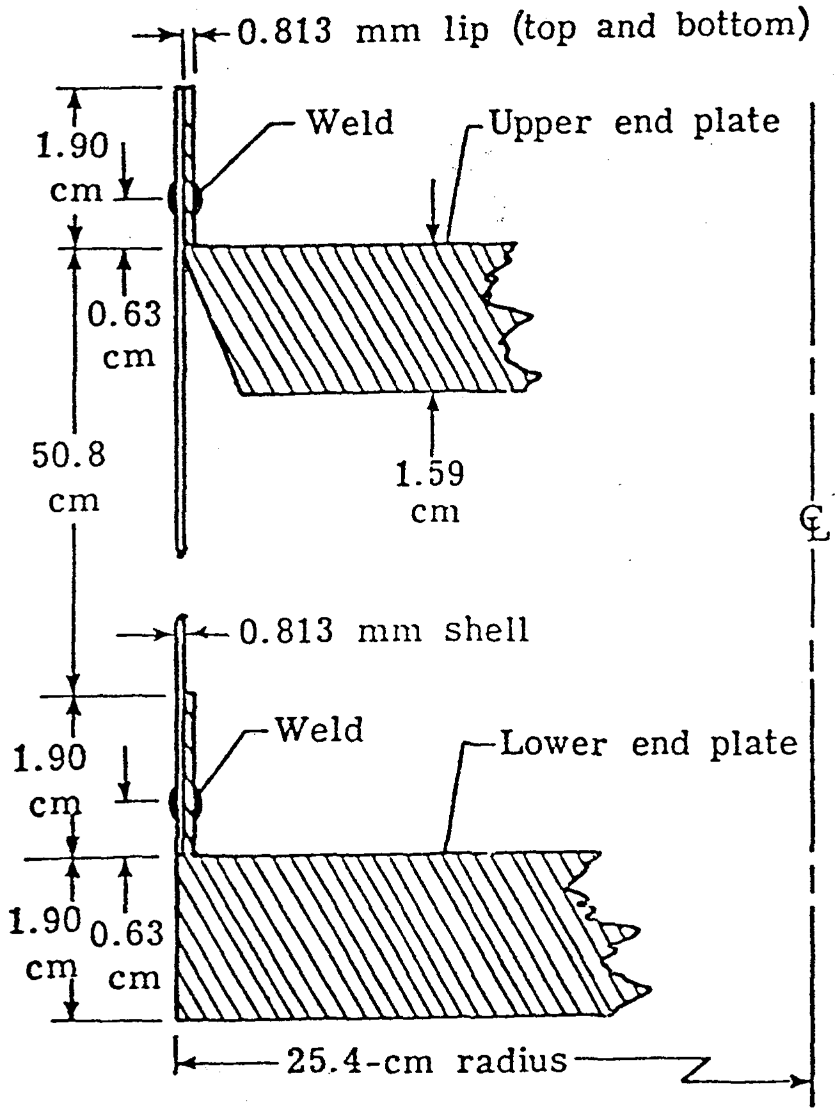

Figure 3.- Construction details of the 6061 aluminum cylindrical tank.

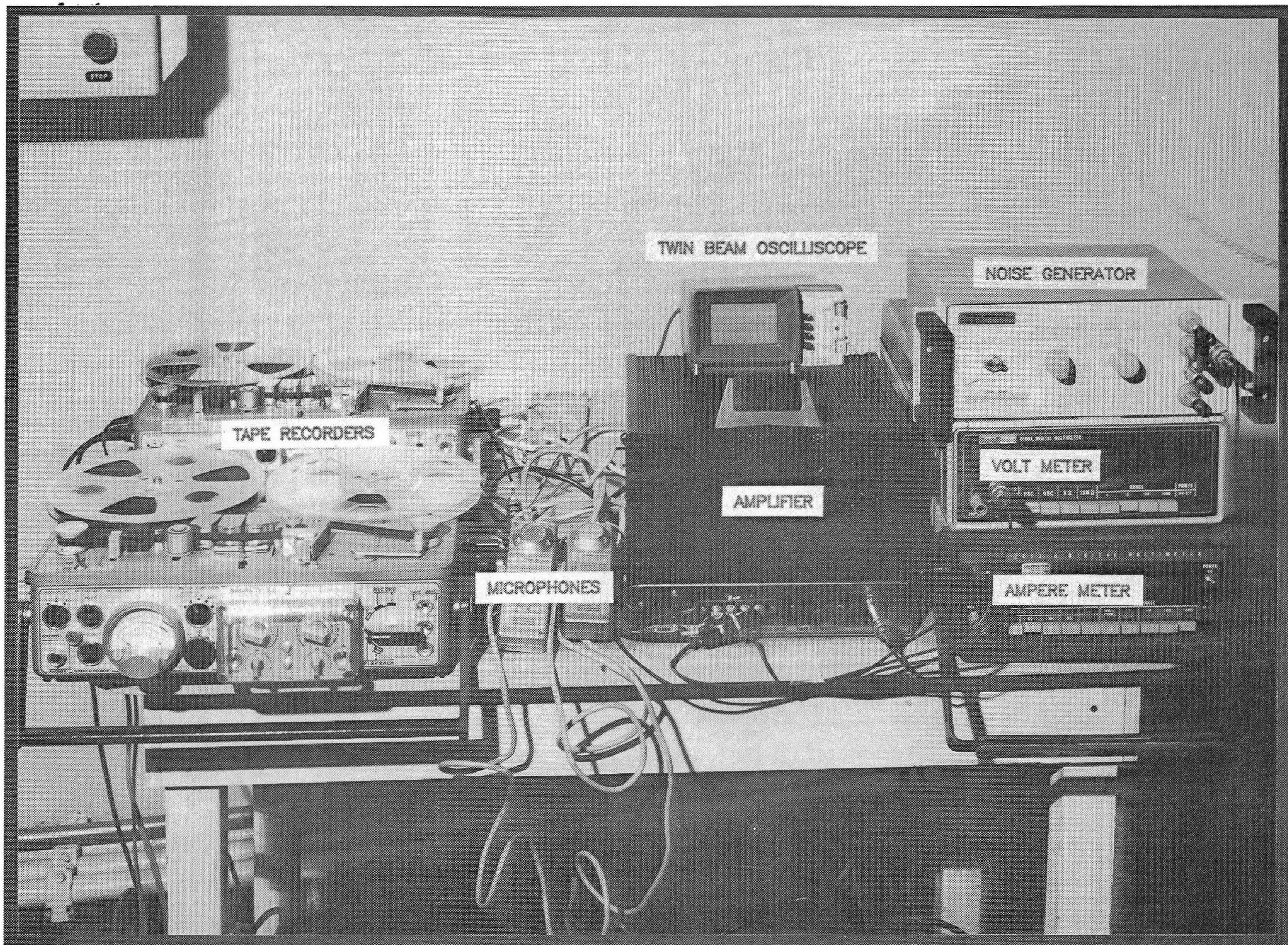

Figure 4.- Instrumentation used in recording and monitoring noise measurements.

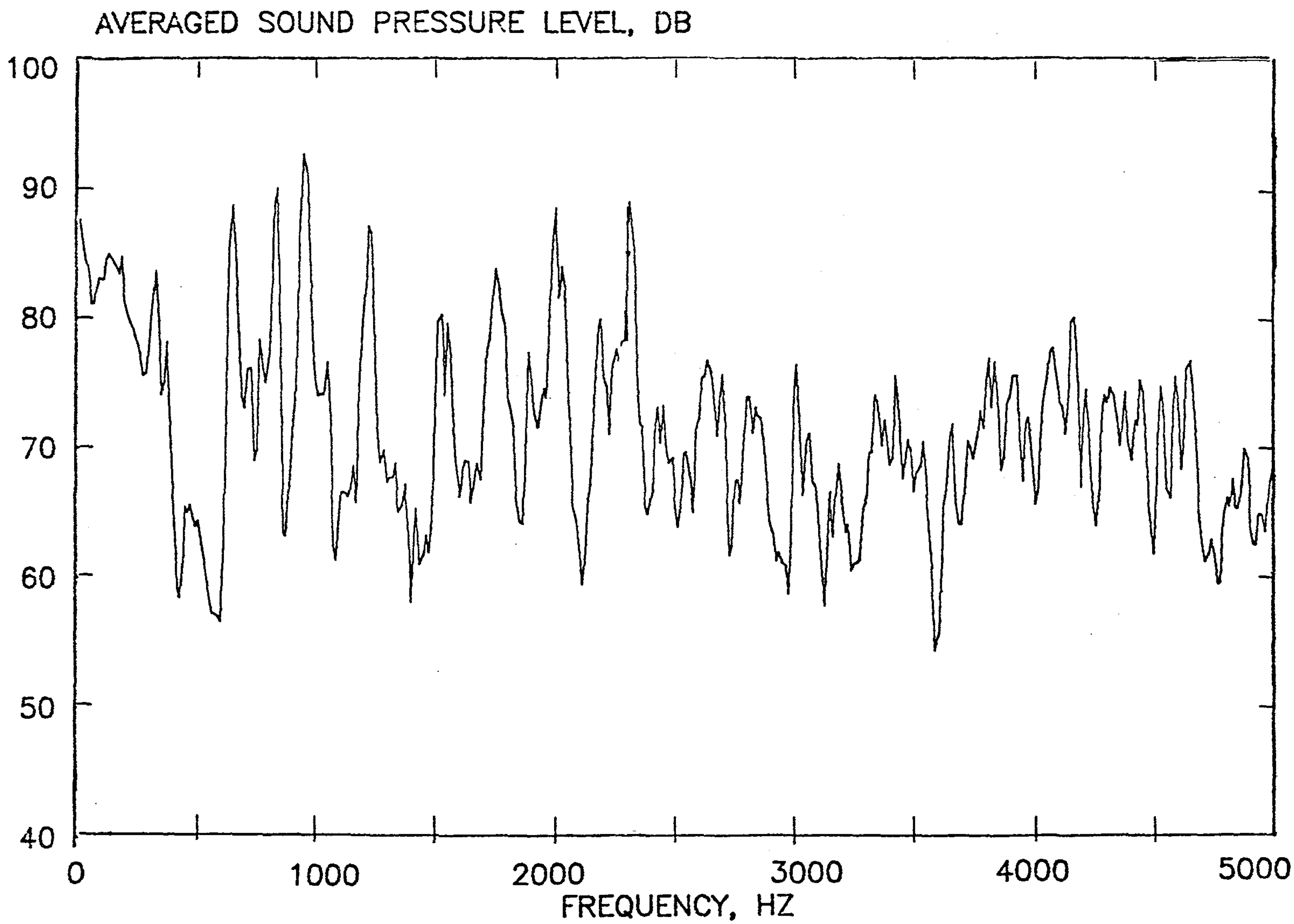

Figure 5.- Example of frequency spectra of noise within the tank.

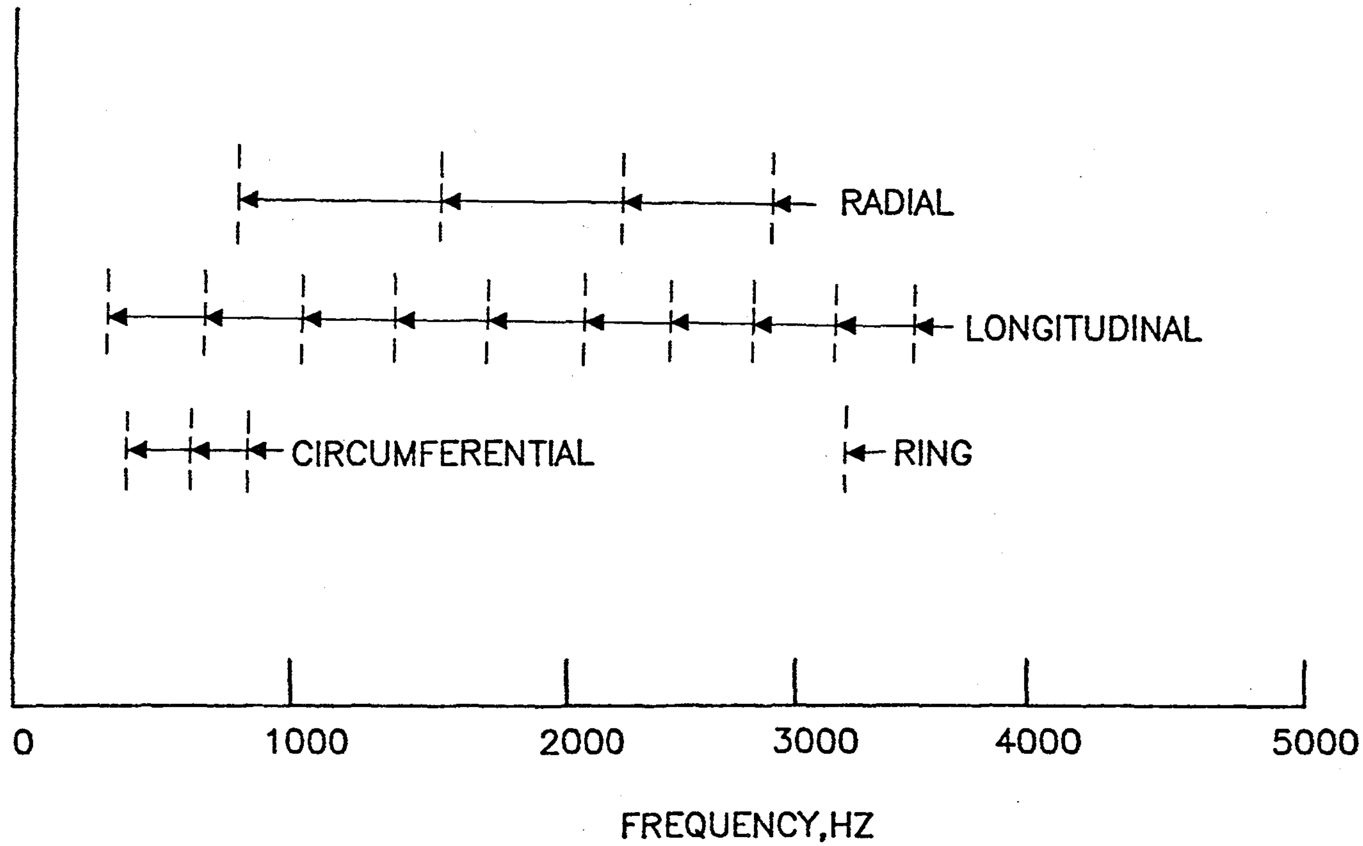

Figure 6.- Calculated modal frequencies of the cylindrical tank.

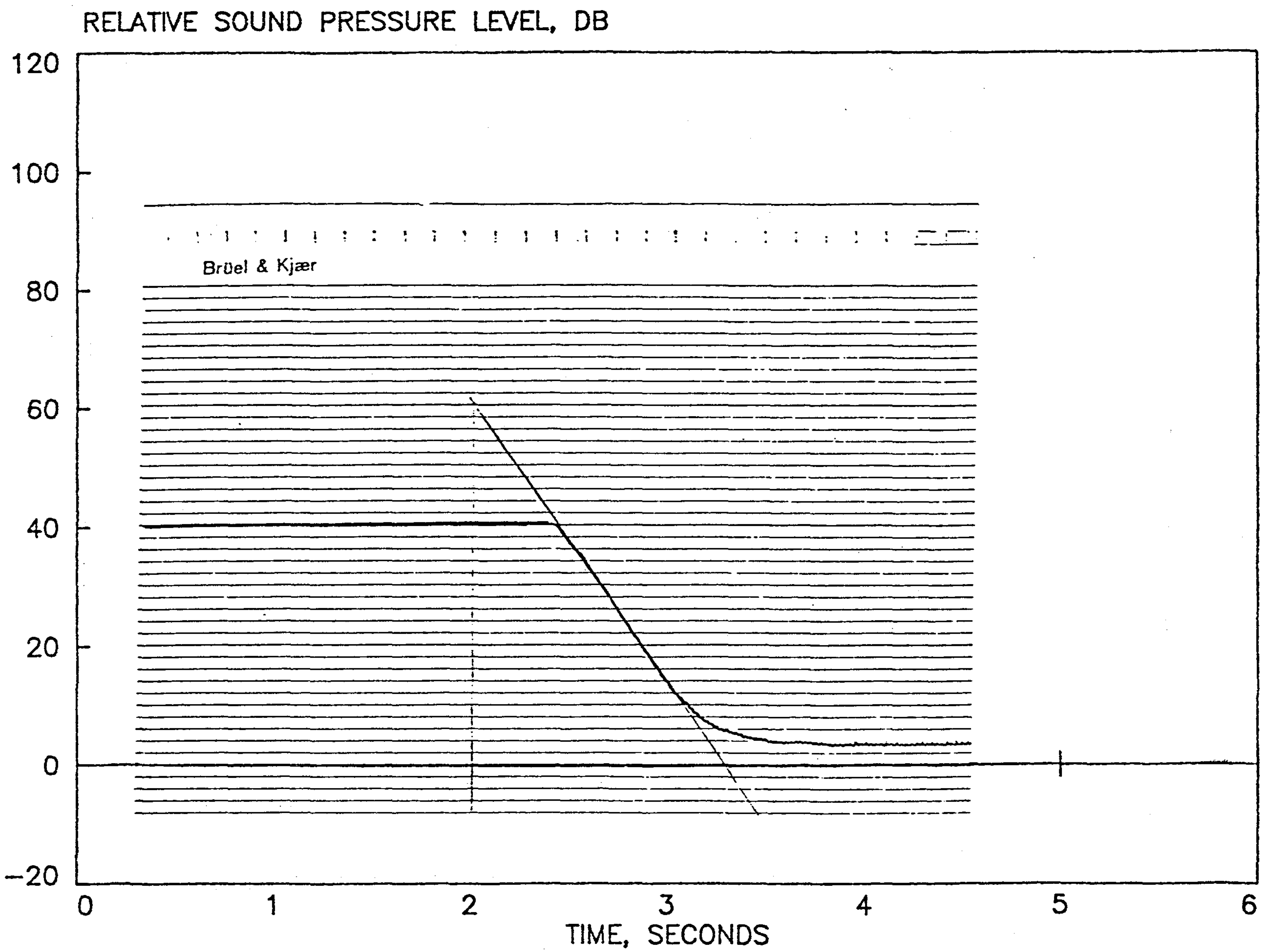

Figure 7.- Example of noise level decay curve inside the tank with an external vacuum environment.

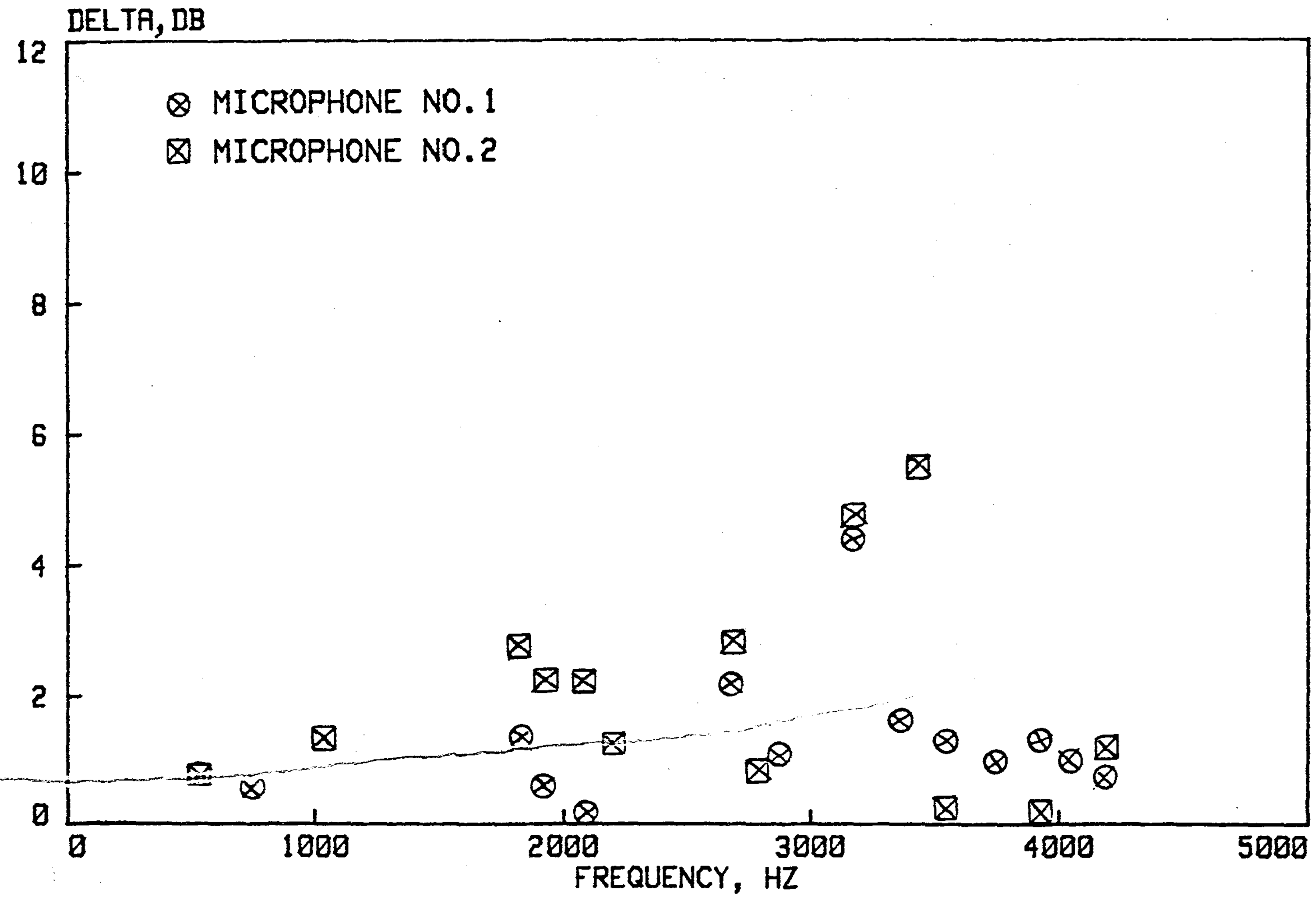

Figure 8.- Difference in level with excitation frequency.

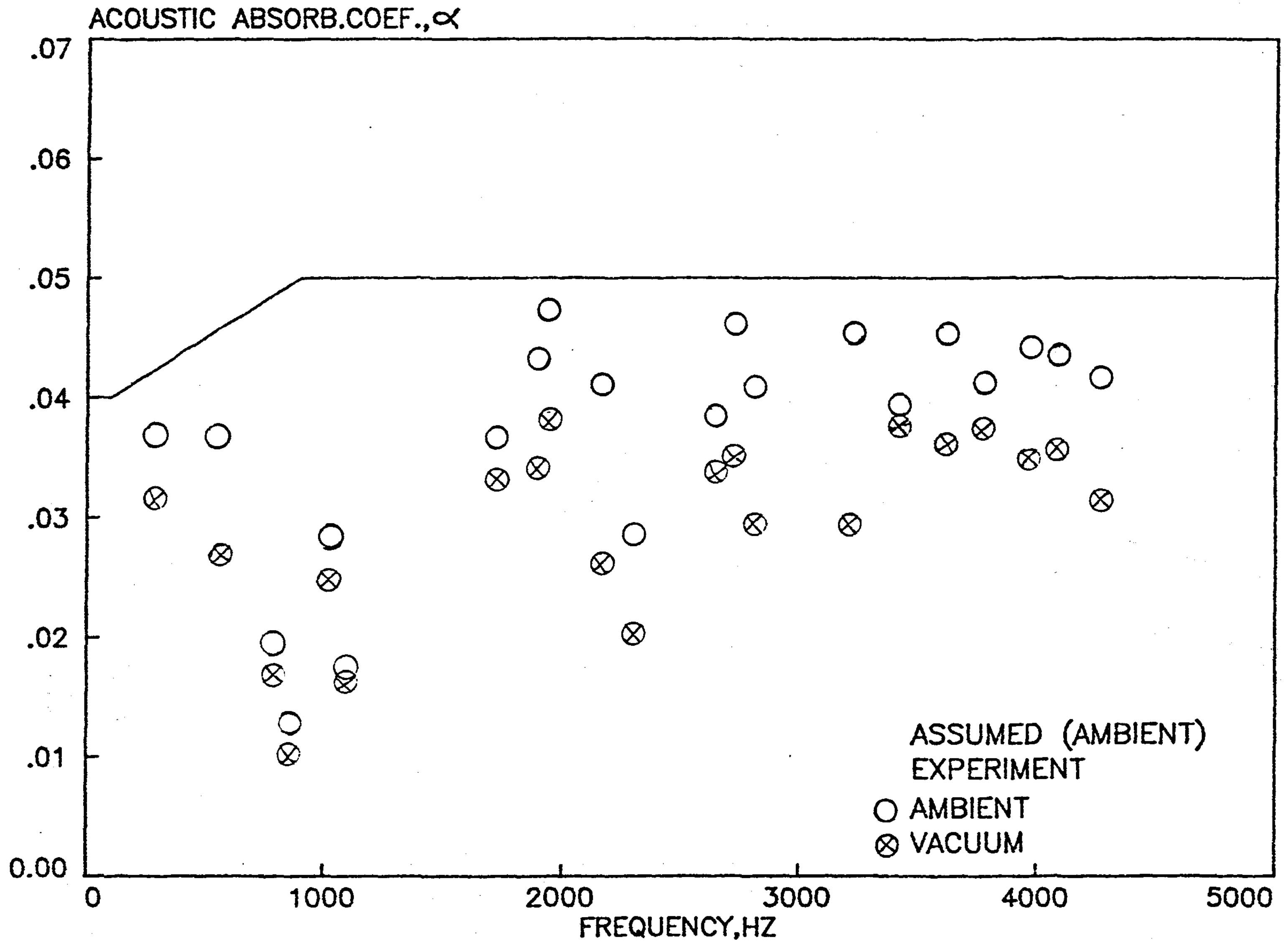

Figure 9.- Absorption coefficient as a function of frequency.

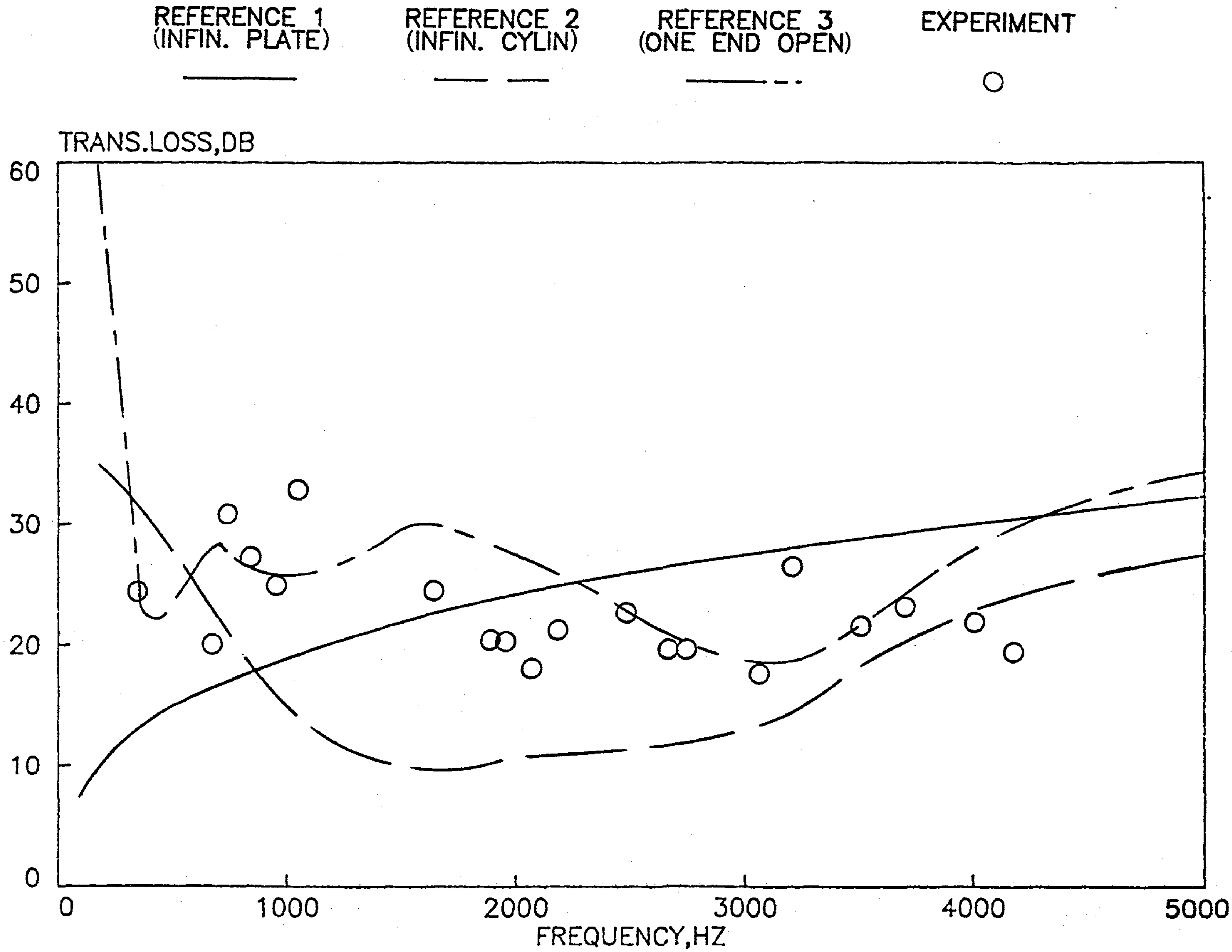

Figure 10.- Transmission loss as a function of frequency.

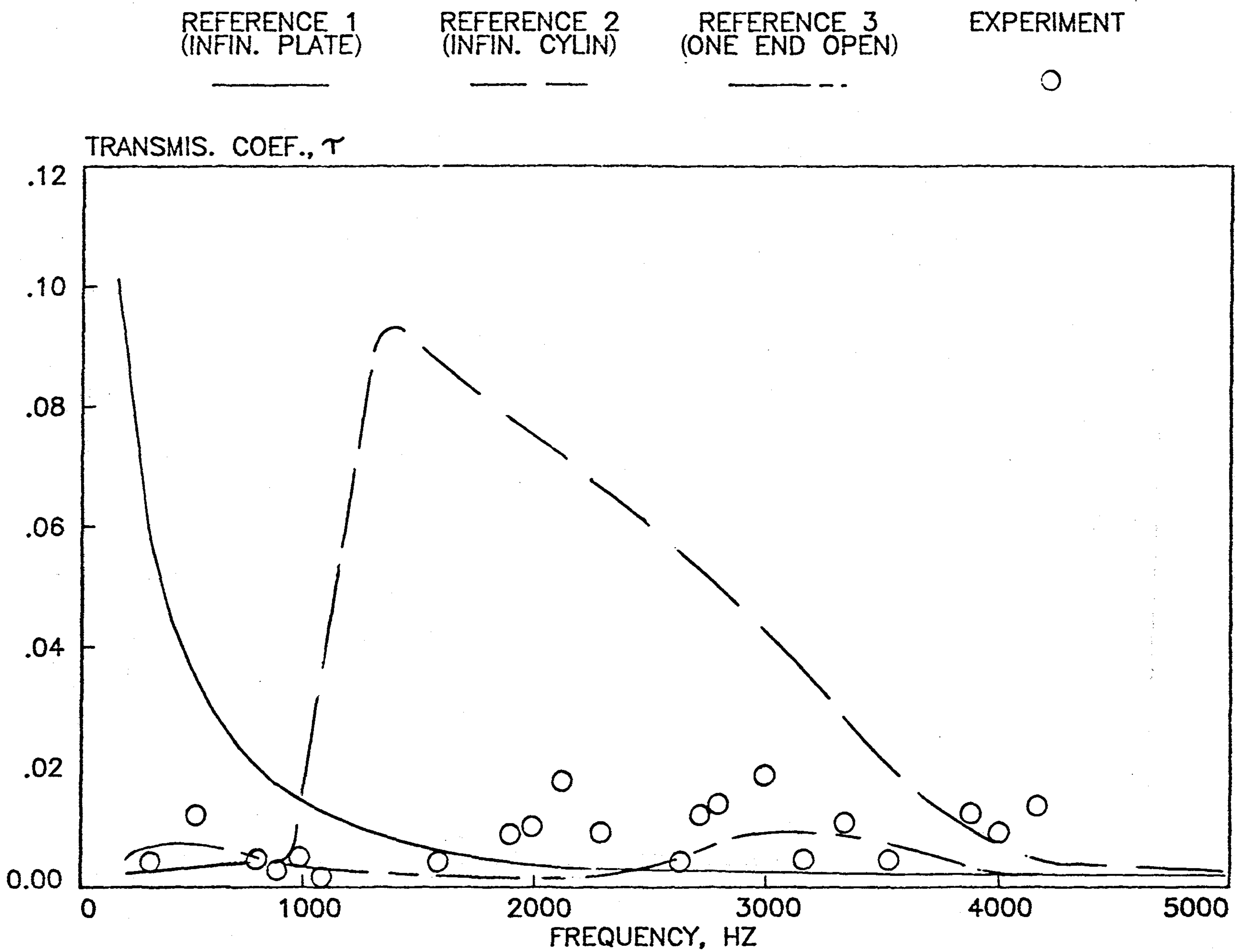

Figure 11.- Transmissibility as a function of frequency.

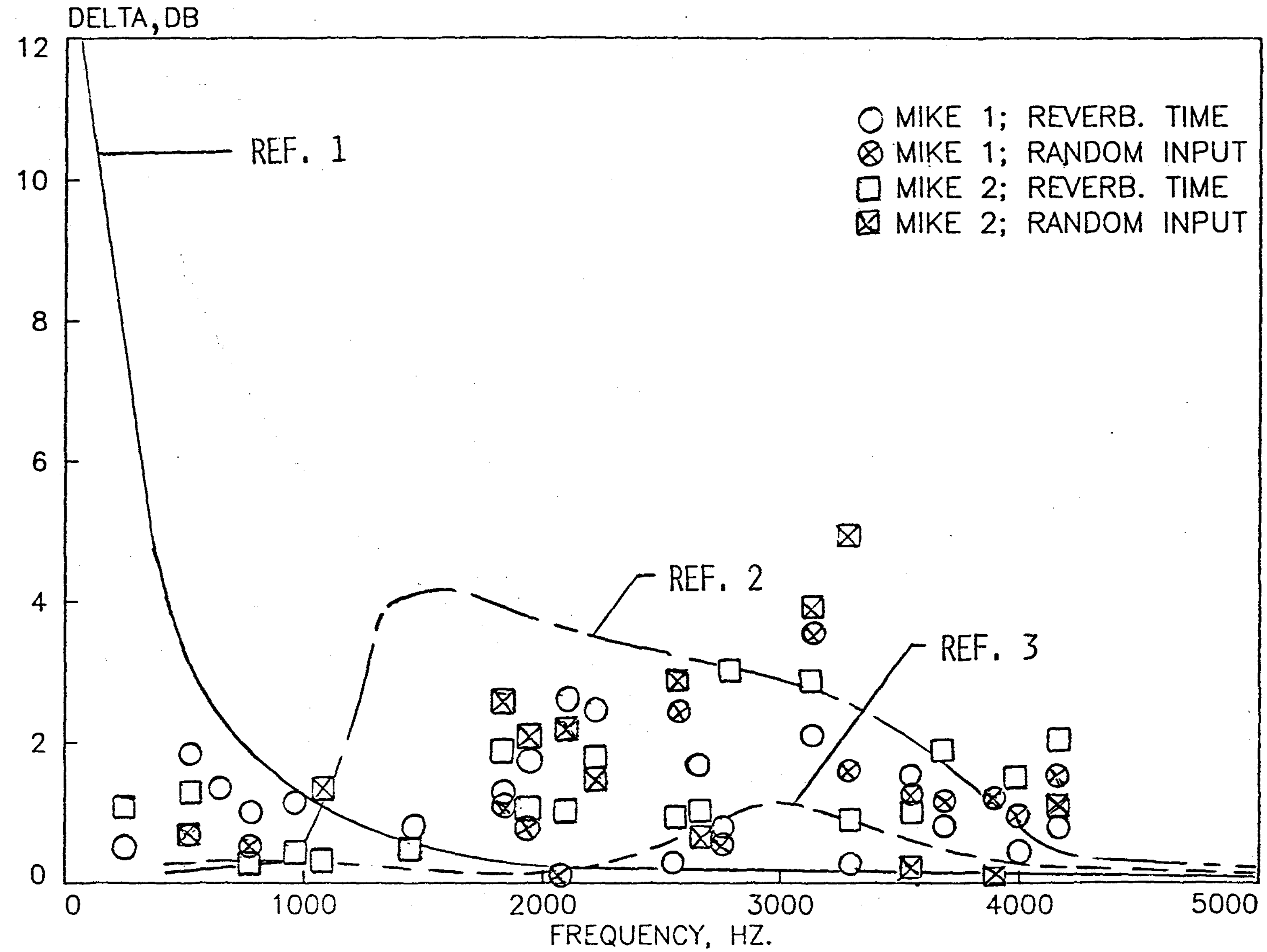

Figure 12.- Comparison of experimentally determined deltas with results of calculations.

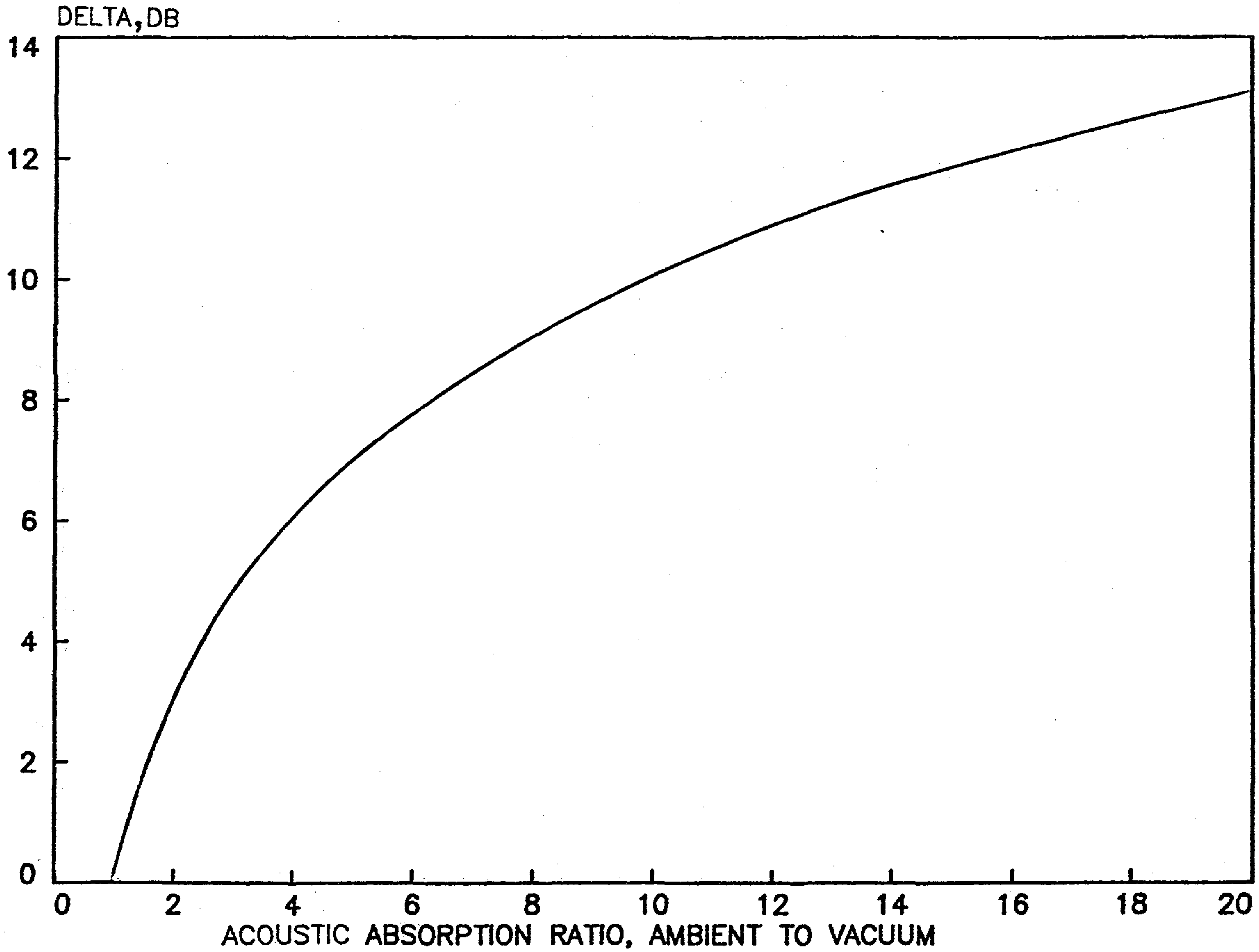

Figure 13.- Calculated difference in noise levels as a function of absorption ratio.

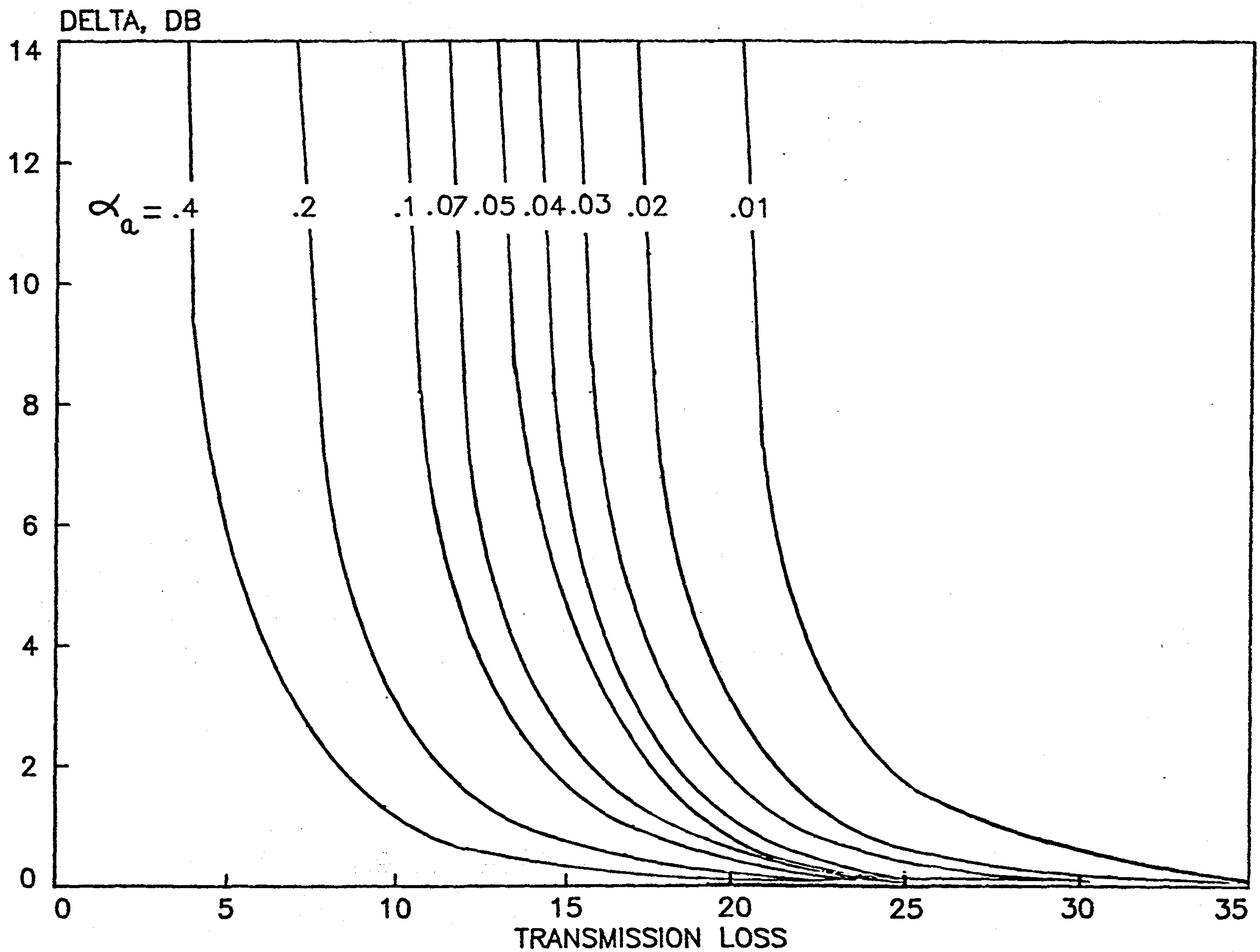

Figure 14.- Calculated difference in noise levels as a function of transmission loss for various acoustic absorption coefficients.

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15. Supplementary Notes

16. Abstract

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